THE GEOLOGICAL *VERSUS* THE PETROGRAPHICAL CLASSIFICATION OF IGNEOUS ROCKS.

THE rocks which make up the solid earth are of interest from a great many standpoints. A large part of geology is more or less directly concerned with them — as to their characteristics, their origin, their relationships in the mass of the earth, the changes in the rocks themselves, either metamorphism or decay, the mechanical destruction of rock masses, and structural changes in the earth dependent in many ways upon the characters of the rocks affected. From all of the points of view just indicated, and from still others, the geologist — often a specialist — has need for a nomenclature by which he may name the rocks as objects, and for various classifications expressing their observed relationships in different directions.

But while an adequate and expressive classification is a matter of great importance to many, it is commonly agreed that the systems of classification and nomenclature now in use are in a state of great confusion — of rapidly increasing confusion. To my mind the principal cause for this deplorable state of things is the lack of a clear conception of the natural relationship between *the systematic* classification of rocks, upon which their *specific* nomenclature must be based, and various *other*, *necessary* classifications of the same bodies. It seems that, while the multiform relations and affinities of rocks and their complex inner nature are more or less clearly understood, the futility of endeavoring to express all of these factors in one system of classification has not come sufficiently to recognition. It is my firm belief that no great progress in systematic petrography is possible until a more rational view of the relationship of that science to geology prevails among its devotees.

What is a rock? This question has often been found difficult to answer in satisfactory form. It is commonly said that

rocks are the materials which make up the crust of the earth, and to distinguish them from minerals it is pointed out that a rock is a geological body—a geological unit. But it is the unit of material or substance, and must be clearly distinguished from the geological unit of form or mass. It is the substance of the geological body, but the two conceptions are not coextensive. Chemical and mineralogical composition and structure are the chief characters of rocks as concrete objects, and it is well known that neither a stratum of sedimentary rock, nor a dike of igneous rock, is necessarily of the same composition or structure throughout. The rock unit cannot be that of the geological body as long as this is true. The rock unit is simply that which the systematic scheme of rock classification finds most desirable and practicable.

It is universally recognized that rocks not only have many relationships, when viewed from the geological standpoint, but that as objects they are extremely complex and variable in character. Lossen has said that the property of transition in all directions is an essential characteristic of the rock. It is quite possible that some who have struggled with systematic problems may be inclined to define the rock as the most variable and indefinite thing in nature! Yet rocks must be classified and named according to some system, and the task is none the less interesting or important because of the difficulties involved. The best system, that most nearly natural and logical, most uniform and stable, must ultimately prevail.

I understand that branch of geology which is concerned with rocks in all their aspects to be petrology—a treatise on rocks—and the narrower systematic, descriptive science of rocks as concrete objects, the basis for their specific nomenclature, to be petrography. This usage has now become so current in this country that discussion seems unnecessary.

Let us pass in review some of the different aspects of rocks which must be considered by the geologist, and at the same time we shall outline the field embraced by *petrology*. (1) There is the rock itself—an object of variable and complex character.

Its constitution — chemical, mineralogical, structural, and physical — must be studied and described. The differences or similarities exhibited by rocks in these respects lead to classes, groups, and lesser divisions, and the expression of these relations to a system of classification and a specific nomenclature. (2) The genesis of rocks is a subject of many phases. The source of materials, the agencies of transportation, the conditions of rock formation, each of these problems must be investigated in detail. (3) The geological occurrence embraces the formal relationships of rock masses to the earth and to each other. (4) The genetic interrelationship of rock types is one of the most difficult questions to deal with. (5) The metamorphism, and (6) the decay or destruction of rocks, each embraces a wide field. To these may be added other important lines of study. It is thus evident that petrology embraces several lines of research, each in some degree independent, each also related to the others. The results may be primarily of value as applied to the general science of geology — the history of the earth, or to the uses of the systematic descriptive science — petrography.

There has long been much discussion as to the objects of rock classification. It has been considered, on the one hand, as a mere mechanism upon which to base a nomenclature, and at the other extreme of view as a means chiefly for the expression of geological relationships of rocks. Mr. A. W. Jackson has said that nomenclature (meaning specific nomenclature) must be wholly divorced from rock classification. But that arrangement of rocks, in accordance with which they are described and their specific names are applied, is in itself the most important of all classifications, *the* systematic classification. The question is as to the criteria to be applied to produce this system. Here there must be general agreement with Mr. Jackson[1] in the proposition, often enunciated before, that a uniform and stable nomenclature must be based on facts and laws, not on theories and hypothe-

[1] On the General Principles of the Nomenclature of the Massive Crystalline Rocks, by A. WENDELL JACKSON, Amer. Jour. Sci. (3), XXIV, 1882, p. 113.

ses. Other classifications may use theoretical criteria and they will often serve useful purposes, nay, they are indeed distinctly necessary to the progress of petrology, but such arrangements must always be considered as subject to revision.

The criteria available for the systematic classification of rocks, fall into two groups, viz., the properties of the rocks themselves as objects, and their relationships to each other and to the earth, which is made up of them. There has always been conflict of views as to the use of these criteria in establishing a systematic classification. In the early years of this century there were two opposing schools, one represented by the German geologist, Werner, who classified all objects in the mineral kingdom as geological bodies, the other best represented by the French mineralogist, Haüy, to whom rocks were purely mineral aggregates. For present purposes it is not essential, however interesting, to trace the development of systematic petrography, but it is worthy of note that the geological classification of rocks is still most strongly advocated in Germany, and the mineralogical classification is still most nearly realized in France.

But the early systems of petrography failed necessarily because based upon ignorance. The material constitution of rocks was but very imperfectly known, and their geological relations were in many respects matters of crude hypothesis. All systems to the present time have failed for these reasons, and the systems of today are not free from the weaknesses due to the application of theoretical criteria.

If we review the situation as regards our present knowledge of the properties of rocks as objects it does not seem too much to say that the development of chemistry and mineralogy, and the application of the microscope to the study of rocks, have given us an accurate insight into their chemical and mineralogical composition, their structure and texture, which cannot be essentially modified by future discoveries. These are the properties universally recognized as most applicable for subclassification.

With respect to the geological relationships of rocks the case

is very different. Those rocks which are surface accumulations are so open to observation that we know many particulars of their origin—the sources of materials, the agencies by which the materials have been brought together, and the processes by which the rock has been made out of them. It is a curious fact that modern petrographers have done little toward formulating an adequate and logical classification and nomenclature for the rocks whose relationships are most evident, while they are continually extending, to an ever increasing degree of refinement, a systematic classification of igneous rocks upon foundations of theory or clear hypothesis. The fact that many criteria now used for the classification of igneous rocks are highly theoretical will hardly be questioned by anyone. From a philosophical standpoint it seems to me evident that such criteria cannot produce a stable system and must in consequence be rejected. A more detailed discussion of this question will follow.

Much has been said in recent years about the legitimate demands of geology upon systematic petrography. What are these demands? Clearly, both geology and petrography have certain reasonable demands to make, the one upon the other, but neither science has recognized its full natural rights, and hence has failed to state them properly. It is the unquestionable right of the geologist to demand of the petrographer a systematic classification of rocks, and a nomenclature expressing it, which shall be as natural and as stable as the controlling factors will allow. The petrographer must claim equal interest in such a system, and his logical counter demand is that he be allowed to construct that system through the application of the criteria best suited to produce the result desired. That is to say, he must reserve the right to reject hypotheses, theories, and even facts, if they are not adaptable.

It has often been said, from the time of the earliest classifications to the present, that rocks must be classified to express geological relationships. I believe that the geologist who today advances such a general proposition as a demand of geology upon systematic petrography is not in fact claiming his just

rights. Rather, it must be said that he does not recognize his rights. He does not perceive the true relationship between geology—petrology—and petrography. Nor does the petrographer who accepts that proposition recognize his rights.

Defining petrology and petrography, as has been done, bearing in mind the complex and variable character of the rock and its manifold relationships, it seems to me that the petrographer should esteem it his duty to produce a systematic classification of rocks with a consistent nomenclature, which shall first of all possess stability. The nearer it approaches to a natural system the better, but the character of the rock precludes the hope of securing a fully natural system. The right of the petrographer under this principle is that he may apply the test of adaptability to each criterion offered. It may be said by some that the ultimate object of petrography must be to secure a thoroughly natural classification, and that when knowledge of the rock is extensive enough such a system will be possible. I believe that that position is incorrect, if, by a natural classification, is meant one expressing all the relationships of rocks. It is not because of ignorance that we cannot set up such a natural system for rocks. The nature of the rock is the cause of this inability, not ignorance concerning it.

The petrologist must classify rocks from every standpoint. He must apply many material facts, all of which cannot possibly be used in the systematic classification of petrography, so many sided is the rock. To illustrate this point, a sandstone is a rock which may be described as inorganic, derived, compound, clastic, stratified, sedimentary, aqueous, surficial, noncombustible, etc., and each of these terms expresses a criterion that has been used in some proposed systematic classification. The petrologist must also classify some rocks on bases of theory or hypothesis, with an expressive nomenclature. For the good of his science he should be able to change such classification and dependent nomenclature as required by advancing knowledge. This amounts to a revolution if the general classification must also be revised in each case. Is it not then a logical principle, for the

good of all concerned, that the systematic classification of rocks, according to which their specific names are applied, must be based on their properties as objects, together with only such geological criteria as may be found adaptable, to the end that the system may be uniform, stable, and as natural as possible.

At this point I wish to digress for a moment and compare the task of the petrographer with that of the zoölogist, the systematic botanist or the mineralogist. From the beginnings of natural history, all natural objects have been subject to classification, at first on the most evident properties, and subsequently according to relationships. The modern zoölogist finds it possible to adopt nearly all of the general groups of animals early set up by the naturalist. Fishes, reptiles, birds, and other groups, needed only to be defined in scientific terms to bring general and scientific usage into harmony. The botanist has not been able to make his system correspond so closely to that of the naturalist. He has found that many natural groups of plants cannot be brought into his system, and he has wisely refrained from redefining the old names for those groups in such a way as to destroy their old and legitimate meaning. Thus trees (silvæ), shrubs, bushes, vines, evergreens, deciduous plants, and others, are not divisions of systematic botany, though recognized as useful and natural groups in the broader science of the vegetable kingdom. The properties and relationships of minerals may be nearly expressed in one system, but, as has been shown, rocks are of such manifold relationships that they defy a single system of classification to a much greater degree than plants.

If we now examine the schemes for the classification of rocks which have been current in the past few decades it appears that geological criteria have frequently been applied to produce the first divisions. It has been plain to all that rocks may be divided primarily into a few great classes on grounds either of geological occurrence or relationship, or of material properties. Each classification has its own justification, but the criteria to be applied in constructing a systematic scheme should plainly be those caus-

ally connected with the properties of the objects which are to be used in the further elaboration of the system. The geological agencies involved in the formation of the rock may be applied to produce rock classes differing in important material characters. This ground of classification has often been used, though not always logically carried out. It produces divisions both stable and natural. More or less distinctly the criterion of geological agency has been applied to form the classes called respectively the sedimentary, igneous and metamorphic rocks. Modern petrography has scarcely modified the old geological classification of sedimentary rocks, it has not yet anything which can be considered a system for metamorphic rocks, but it has elaborated a detailed scheme for igneous rocks, and it is now desired to review this system on the basis of the principles already presented.

Geological age has been commonly used as a criterion for the first subdivision of igneous rocks. It was originally applied in the belief that the older rocks differed in certain inherent and essential properties from younger ones. It was assumed that certain material characters were in some unexplained way governed by this geological factor, which thus became of prime classificatory value. But nearly all petrographers now perceive that assumption to have been unwarranted, and few would advocate a division of igneous rocks by age were it not for the double nomenclature in existence. It is difficult to agree upon the details of the simplification in this respect which all realize must eventually be effected.

It is in regard to the importance and applicability of geological form or place of occurrence and association of types as criteria for systematic classification that the greatest differences of opinion may be found among petrographers of today. The former of these factors, form or place of occurrence, has been and is still applied to the classification of igneous rocks on the ground that it is determinative of certain characters of rocks, and especially of structure, to a degree demanding recognition in this way. This usage is best represented by the well-known system of Prof. Rosenbusch by which massive or eruptive rocks

are divided into three great classes: "Tiefengesteine," "Ganggesteine," and "Ergussgesteine." These terms are commonly translated into English as Deep-seated rocks, Dike rocks, and Effusive rocks. Let us examine this classification from the different standpoints of the systematic petrographer and the petrologist.

To begin with it is self-evident that these class names express geological occurrence. They represent natural divisions of the geologist, they were used by him long ago and must be used in future, to express natural relationships. The geologist has a logical and practical claim upon these terms which cannot be denied. The question then is, can this geological classification be applied to the uses of systematic petrography, producing natural classes of rocks, a result which would be of great benefit to all concerned. I believe that it cannot be so used.

The system of Professor Rosenbusch is avowedly intended to meet the legitimate demands of geology upon his systematic science, as formulated by Lossen, to the effect that geological relations of rocks must be recognized as petrographical relations.[1] But while aspiring to meet the conceded demands thus expressed Rosenbusch has so redefined each of these grand divisions that it does not include all rocks belonging in it upon the criterion most clearly expressed in the name, the criterion the geologist must apply, and does include rocks that cannot logically be placed there. To illustrate by the most striking instance, the Dike rocks of Rosenbusch are not rocks occurring in dikes, which must be the geologist's definition, but rocks of as yet hypothetical derivative relation to certain other rocks. This class includes a small part of the rocks actually occurring in dikes and many not so occurring. Similarly the Deep-seated rocks of Rosenbusch are not necessarily abysmal. They appear in dikes and other intrusive bodies near the surface and even in some effusive masses. The Effusive rocks of this system occur in many intrusive masses and in the peripheries of deep-seated

[1] Über die Anforderungen der Geologie an die petrographische Systematik. Jahrbuch der K. pr. geol. Landesanstalt, 1883, p. 486.

bodies. That the above statements are true is abundantly admitted by Professor Rosenbusch in the pages of his "Mikroskopische Physiographie der massigen Gesteine."[1]

The classes of igneous rocks established by Rosenbusch upon the criterion of geological occurrence are not those of the geologist. But it is well understood by all familiar with the subject that an assumed relation between geological occurrence and structure of igneous rocks lies at the basis of Rosenbusch's inconsequent definitions of the three classes under discussion. In fact, the petrologist studying the genesis of igneous rock structures knows that they result from a complicated set of chemical and physical conditions attendant upon the consolidation of molten magmas. These conditions are as yet only partially understood. Pressure, absolute temperature, rate of cooling, the chemical changes in the fluid residue owing to fractional crystallization, the influence of so-called mineralizing agents, and several other factors, are recognized, but their relative importance is yet a matter of theory or hypothesis. A predominating influence was not long ago assigned to pressure, measured by distance from the earth's surface. But it is now known that that condition is in itself of little importance, within the zone of the earth's crust of which we have definite knowledge. It is also known that the conditions of consolidation are not controlled by either geological form or place of occurrence, to an extent capable of definite statement. The petrologist must recognize that while the typical granular structure is most common in abysmal igneous masses it may develop and is often found in the intrusive bodies of the intermediate zones of the crust and in surface masses. Nor has size of the molten body a determining influence. Neither are the porphyritic or fluidal structures dependent upon the geological form or place of occurrence of rocks exhibiting them.

Since the petrologist must inevitably apply the geological

[1] The natural limitations of the present discussion prevent an analysis of the considerations which led the German master to propose such a classification, but a review of the Rosenbusch system upon the principles here presented is now in preparation and will soon appear in this JOURNAL.

criteria of form and place of occurrence for the classification of igneous rocks into certain logical and natural groups, and has for this purpose a consistent language and mode of expression, he must surely demand of the systematic petrographer that these criteria shall not be used to produce another classification with other definitions of the same terms. Such a course produces confusion for which there can be no justification. It is to me utterly incomprehensible how the appropriation and redefinition of the geologist's terms and nomenclature can have been carried through as in the Rosenbusch system under the idea that thereby the science of geology would be benefited. And where is the science of petrography benefited by the formation of systematic groups which are confessedly unnatural and wholly unnecessary?

The petrologist must express the facts of the relationship between rock structure and geological occurrence, as between structure and other factors, to the best of his knowledge at any given time. It is not to his advantage to have this relation, always to be a matter of interpretation or theory to some degree, expressed in the systematic scheme. Nor can it be to the advantage of the system, for it will be a cause of instability.

The genetic interrelationships of igneous rocks, which most petrologists believe to be the result of what is called magmatic differentiation, are most important, but are clearly of hypothetical nature, and must remain at best matters of theory as long as the origin of the earth itself is veiled in mystery. It seems to me utterly impossible to admit such factors into the petrographic system. But it is the tendency of several leading investigators of today, notably of Rosenbusch and Brögger, to make these theoretical relationships more and more prominent in systematic classification, and from the considerations above presented I wish to make most earnest protest against this tendency as really contrary to the best interests of both geology and petrography. In thus protesting, I must not be understood as failing to appreciate the great advance in our knowledge of the origin of igneous rock varieties and of their structures, and

of the genetic relationships of types which has come within the past few years largely as a result of a promulgation of the theoretical ideas lying back of the systematic scheme advocated by Rosenbusch. One may well deny the desirability of the Dike rock group of Rosenbusch and be at the same time an ardent advocate of the theories upon which the group was established, and which have little connection with the fact of geological occurrence expressed in the name. Classifications of rocks, expressing working hypotheses as to their genesis, are necessary and may be set up at will if disconnected with the systematic classification. A stable nomenclature for rocks as objects will facilitate rather than hinder development of theoretical science.

I believe, then, that geological occurrence is not a practicable criterion for systematic classification of igneous rocks, and that it has been applied to that purpose through a misunderstanding of the true position of systematic petrography to the broader science of rocks. The petrographer has for many years failed to perceive, or, at least, to acknowledge, the right of the geologist to any special nomenclature of rocks. He has taken the time-honored terms of the geologist, redefined them to suit his own special purposes, until the geologist who is not a petrographer is almost afraid to use the simplest and most plainly denotive terms lest he be denounced as unscientific. But I maintain that it is the petrographer who has been unscientific, when he has misappropriated the natural nomenclature of the geologist, and when he has defined structural terms to express a genetic theory, or has applied them to certain rocks only out of all those possessing the structures in question. The definition of the granular structure as one having a certain mode of origin, instead of stating what the structure really is; the appropriation of *granulite* and *granite* for certain granular rocks, leaving no appropriate name for all rocks of that structure; the misuse of *porphyry* in analogous ways,—these are illustrations of thoroughly undesirable precision of definition, undesirable because at the expense of the geologist who has a prior and logical claim to these terms and needs them in their original senses.

RÉSUMÉ.—Rocks are too complex in their characters and have too many and too varied geological relationships to permit of one systematic classification expressing all their properties and relationships. A primary division on geological grounds may be carried through, producing classes of different characters, and such a division is universally advocated.

Since all the geological relationships cannot possibly be used in one system, it appears that a distinction must be made between that classification by which rocks are grouped for purposes of description and naming as concrete objects, and all other classifications. The former may be called the systematic classification, and I consider petrography to be the science presenting and applying that system to the description and naming of rocks. The broader science of petrology, using the nomenclature of petrography for specific purposes, must arrange rocks in as many other ways as are desirable to express their characters or relationships not introduced into the systematic scheme, and for the expression of these other arrangements a separate terminology is essential. It must not be appropriated under redefinition by the petrographer.

The material properties of igneous rocks afford ample criteria for establishing a systematic classification, and the use of geological relations is unnecessary. Since the geological factors of age, or of form or place of occurrence are not directly causes of the properties used in classification, they cannot be applied to produce coördinate groups. The attempts to thus apply them have been unfortunate. The justification of these attempts has been the belief that geology demanded that geological relations be recognized as petrographical relations. In the view above set forth this belief is illogical, and has resulted in injury both to geology and systematic petrography.

The impossibility of setting up an all-embracing natural classification of igneous rocks is not due to ignorance. It comes from the nature of the rock. The more we know the less shall we be able to include all relations in one classification.

WHITMAN CROSS.